UNIVERSALITY, BIFURCATIONS, TACHYON

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Challenges

- pQCD calculations produce amplitudes for the scattering of colorless dipole off a hadron target rapidly increasing with collision energy approximately as power of energy. This property follows from gluon spin 1 , multiparticle production and slow convergency of integrals over momenta of exchanged gluons.

- In practice, after account of energy-momentum conservation , this increase is in conflict with probability conservation when few gluons are radiated. The nonlinear condition accounting for the probability conservation follows from the relationship between Green functions.

- The conflict with probability conservation arises within both LO +NLO DGLAP or BFKL approximations in the domain where analytic calculations are feasible.

Approximations used to restore probability conservation in pQCD at large energies like eikonal approximation even with account of inelastic diffraction are unstable. To visualize this point we present example illustrating that it is possible to obtain any answer from pQCD series at sufficiently large energies:

$$f(y) = \sum c_n y^n (-1)^n = 1/1 + y$$

$$\text{if } c_n = 1 \text{ But for } c_n = 1 + (-1)^n \epsilon^n$$

$$f(y) = 1/(1 + y) + exp(\epsilon y)$$

Thus even for arbitrary small ϵ two functions are vastly different. Remember that account of energy-momentum conservation and inelastic diffraction introduces significant uncertainties into evaluation of each term in the generalized eikonal series.

This instability suggests presence of bifurcation, and/or new (as compared to low energy QCD) degeneracy of vacuum ➳ zero mode

So our strategy is to find model independent consequences of the regime where the interaction is rapidly increasing with energy and separately to consider QCD inspired model for oversimplified phenomena to investigate origin of instability of pQCD series .

Model independent predictions. F.S.Z 04

Fast increase of interaction with energy leads to complete absorption at fixed impact parameter. Thus partial wave at given impact parameter becomes universal-equal one. Observed

✦ in the elastic pp collisions at FNAL -soft QCD,

✦✦ indirectly in the colorless gluon (but not quark) dipole scattering off a proton target in DIS at HERA-hard QCD .

✦✦✦ in the correlation measurements in dA collisions at RHIC-hard QCD .

M.Strikman talk, this conference ,F.S.(06).

Complete violation of conformal symmetry in DIS at small x.

$$F_2(x, Q^2) = cQ^2 \ln^3(x_0/x)$$

The ratio of structure functions of hadrons, nuclei tend to one i.e. coefficient "c" should be the same for hadrons and nuclei at extremely small x. Universality follows from the universality of partial waves due to complete absorption of colorless dipole, of increase with energy of impact parameters and dominance of universal pion tail in the structure functions at large impact parameters.

Coefficient "c" should become universal i.e. the same for any hadronic projectile and target.

$$\sigma = c \ln^2(s/s_o)$$

$\ln^2 s$ follows from

(a) complete absorption resulting from the fast increase of amplitudes with energy leading to partial amplitudes at fixed impact parameter $\to 1$.

(b) increase with energy of essential impact parameters due to Gribov diffusion in ladder and increase with energy of partial amplitude.

(c) At large impact parameters dominates universal Pomeron exchange and at asymptotically large energies possibly pion tail. This reasoning explains observed small coefficient in the Froissart formulae for
total cross section of pp collisions.

Froissart formulae should be valid for the total cross sections of hadron-hadron, hadron-nucleus collisions

$$\sigma = c \ln^2(s/s_o)$$

"c" is universal = the same for any hadronic projectile and target. It follow from

(a) complete absorption resulting from the fast increase of amplitudes with energy leading to partial amplitudes at fixed impact parameter $\rightarrow 1$.

(b) increase with energy of essential impact parameters due to Gribov diffusion in ladder and increase with energy of partial amplitude.

(c) dominance of Pomeron exchange at large impact parameters.

This reasoning explains observed small coefficient in the Froissart formulae for total cross section of pp collisions.

Universality of cross sections has been suggested by V. Gribov within the Pomeron calculus for the case of hadronic cross sections becoming constant at high energies. In the case of cross sections increasing with energy universality is almost trivial consequence of QCD.

Disappearance of Landau-Pomeranchuk coherence in the propagation through a medium of a parton produced in a hard interaction . Violation of LP coherence is due to important role in small x hard processes of absorptive effects and fractional energy losses . (F.S.06)

To visualize new phenomena we investigate high energy scattering of small dipoles of the same transverse size to suppress evolution in transverse plane. pQCD amplitudes can be approximated as calculable power of energy -bare "Pomeron".

Account for pQCD ladder as quasiparticle and interactions between ladders as many ladder vertexes leads to an effective field theory:

B. Blok & L.Frankfurt 05

$$
\begin{aligned}
L &= 1/2(p\partial_y q - q\partial_y p) - \alpha' p\triangle_b q - \mu pq - \kappa pq(p+q) \\
&- c_{\rm dipole}\int \exp(-bQ/2)q(y,\vec{B}-\vec{b})d^2b\delta(y+Y) \\
&- c_{\rm dipole}\int \exp(-bQ/2)p(y,\vec{B}-\vec{b})d^2b\delta(y-Y),
\end{aligned}
$$

This Lagrangian accounts for fast increase with energy of the gluon ladder, the Gribov diffusion within ladder in transverse plane, increase with energy of impact parameters due to increase of interaction, triple ladder self interaction and source terms. p,q are the operators of production or annihilation of ladder.

This Lagrangian is exact within WKB approximations because of smallness of running coupling constant.

In QCD within the WKB approximation accounting for causality and energy-momentum conservation many ladder self interactions are suppressed by the power of running coupling constant.

$$\kappa \propto \frac{\alpha_s^2 N_c}{\lambda}, \quad G_{4P} \propto \frac{\alpha_s^4 N_c^2}{\lambda^3}, \quad G_{nP} \propto \frac{\alpha_s^{2n-4} N_c^{n-2}}{\lambda^{n-2}}.$$

The form of effective quantum field theory of hard processes coincides with triple Pomeron model of soft QCD processes considered by (D.Amati,....) but evidently it has different meaning and different parameters.

Analysis of the model within WKB approximation found that in the approximation when triple ladder vertex is neglected pQCD produces tachyon. Account of triple ladder vertex leads to the existence of several degenerate extrema -"vacuums":

$$(a)\, p = 0, q = 0;\ (b)\, p = \mu/\kappa, q = 0;\ (c)\, p = 0, q = \mu/\kappa.$$

This bifurcation is relevant for the discussed above instability of series over rescattering effects. Thus small x QCD is the field of kinks, of two dimensional massless "phonons":

$$E = 2i\sqrt{\alpha' \mu\kappa}.$$

of critical phenomena -Bose-Einstein condensation of ladders. Account of degeneracy between 3 extrema leads to Goldstone boson relevant for Froissart limit, color inflation and related kinks. cf.-talk of B.Blok at this conference.

If we neglect by dependence of impact parameter distribution on energy, the considered model is exactly solvable within WKB approximation. This is because in this case field theory is reduced to a one dimensional quantum mechanical problem - **Blok & LF 05**

This approximation rapidly gained in popularity. It appears to be a subject of several talks at this meeting.

Distinctive features of the model is the presence of kinks which lead to nonperturbative effects.

A kink produces:

- action proportional to $(\mu/\kappa) \sim (1/\alpha_s)$
- step function in rapidity space of the width:

$$\delta Y \approx \log(\delta E/Q) = 1/\mu$$

Calculations show that density of produced ladders is large:

the transverse distance between the ladders is

$$l_t \sim \kappa/\mu \sim \alpha_s/\lambda$$

On the other hand, the characteristic scale d_t of a ladder in the transverse parameter space is determined by the coefficient in the effective Lagrangian in front of the kinetic term, that is $\sim N_c\alpha_s/\lambda^2$,

$$d_t^2 \sim N_c\alpha_s/\lambda^2$$

Consequently,

$$l_t^2/d_t^2 \approx \alpha_s/N_c \ll 1.$$

Thus pQCD ladders overlap significantly. Overlapping ladders may exchange quarks and gluons because there are no barriers between ladders. Result is formation of color network- melting of ladders.

Conclusions

Popular pQCD approximations produce tachyon in partial amplitudes of colorless dipole-dipole scattering in the crossed channel.

Self interactions between ladders lead to several degenerate "vacuums" and to the critical phenomena related to choice of "right" vacuum, to the condensation of ladders with strong overlap in impact parameter space between ladders.

Accounting gluon exchanges between ladders transforms system of overlapping ladders into color network which is probably actual solution of QCD equations at extremely large energies.